ENHANCED MARS RADAR OBSERVATIONS WITH THE GOLDSTONE SOLAR SYSTEM RADAR: GROUND-BASED STEPS TO A RADAR MAP OF MARS. A. F. C. Haldemann, R. F. Jurgens, F. S. Anderson and M. A. Slade, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109-8099, USA. Email: albert@shannon.jpl.nasa.gov

Introduction: The Goldstone Solar System Radar (GSSR) has successfully collected radar echo data from Mars over the past 30 years. As such, the GSSR has played a role as a specific mission element within Mars exploration. The older data provided local elevation information for Mars, along with radar scattering information with global resolution (e.g. [1,2]). Since the upgrade to the 70-m DSN antenna at Goldstone completed in 1986, Mars data has been collected during all but the 1997 Mars opposition. Radar data, and non-imaging delay-Doppler data in particular, requires significant data processing to extract elevation, reflectivity and roughness of the reflecting surface [3]. The spatial resolution of these experiments is typically some 20 km in longitude by some 150 km in latitude. The interpretation of these parameters while limited by the complexities of electromagnetic scattering, do provide information directly relevant to geophysical and geomorphic analyses of Mars.

Landing Site Assessment with Radar Data. The usefulness of radar data for Mars exploration has been demonstrated in the past. Radar data were critical in assessing the Viking Lander 1 site [4, 5] as well as, more recently, the Pathfinder landing site [6, 7]. In general, radar data have not been available to the Mars exploration community at large. One of us (Haldemann) has recently finished a project funded by the Mars Exploration Directorate Science Office at the Jet Propulsion Laboratory (JPL) to reprocess to a common format the last ten years worth of raw GSSR Mars delay-Doppler data in aid of landing site characterization for the Mars Surveyor Program. The radar data used were obtained since 1988 by the GSSR, and comprise some 73 delay-Doppler radar tracks.

Enhanced Radar Observations: Two modern radar techniques offer the opportunity to improve the spatial resolution and the global coverage of available radar data: random-long-code delay-Doppler observations, and interferometric delay-Doppler observations.

Random-long-code delay-Doppler radar. In standard delay-Doppler observations, Mars is overspread [8]. This can be overcome by using a pseudo-random, non-repeating code that is much longer than the observing run. This technique was successfully applied to Mars by Harmon et al. [9] to image the Martian surface at 39 km resolution with the Arecibo Observatory at 12.6 cm wavelengths. The GSSR used the technique at 3.5 cm during the 1999 opposition [10]. Dual-polarization coded long pulse data were collected. The 1999 opposition provided the opportunity to observe Mars at high northern sub-radar latitudes, providing a good view of the north polar region. The campaign resulted in 14 days of data over the course of a month. The GSSR 25 kHz baud rate used in 1999 had the potential to produce 12 km resolution cells in the polar regions. For signal-to-noise reasons, the actual cell size was 48 km. The random-long-code technique is particularly useful for obtaining radar information away from the sub-Earth radar track at moderate to high latitude. The north-south ambiguity inherent in delay-Doppler is still manifest, and so the technique really lends itself to observations of bright features on the surface.

Interferometric delay-Doppler radar. Observing the radar echo with more than one receiver provides a means to remove the north-south delay-Doppler ambiguity. Sixteen of the 73 radar tracks in the recently re-assembled radar dataset are interferometric radar tracks. The interferometric information has never been processed, because the signal to noise is insufficient to constrain both the phases and the radar scattering parameters. The new topographic data from the Mars Orbiter Laser Altimeter (MOLA) on the Mars Global Surveyor (MGS) spacecraft offer the best means to analyze these unused data to make radar maps that extend the radar properties coverage some 3 to 4 degrees beyond the sub-earth radar track. This would be a significant expansion of the dataset, and is all the more warranted as the radar spatial resolution improves away from the sub-Earth track (smaller range ring-Doppler strip intersections away from the sub-Earth track). At the outer edges the radar resolution cell is of the same order of size as the landing site ellipses for future mission (approximately 20 km diameter).

Future Data Coverage: The 2001 Mars opposition offers an opportunity to fill in some areas where radar data are lacking in the current dataset. In particular the latitudes of the so-called 'Haematite Site' will be covered by the radar near opposition. We are currently planning 18 radar tracks between May and July of 2001. The latitude and longitude coverages for each planned track are listed in Table 1. The goal of the observations will be to provide as much new, interferometric, improved-spatial-resolution radar data over the 'Haematite Site', as well as over the region also previously considered for the 2001 Surveyor lander on the rim of the Isidis Basin.

Significance: Mars radar data from the GSSR, as well as from the Arecibo Observatory, can and should be considered as specific mission elements of any Mars program. The topographic information that delay-Doppler radar used to provide for Mars missions is now superceded by MOLA. However, the data from that instrument offer a means to bootstrap radar data to higher spatial resolution: use of MOLA topography in conjunction with interferometric observations means that future observations can derive radar scattering information near the sub-Earth track with ~30 km resolution cells and without north-south ambiguity along the radar track. Random-long-code observations reach similar spatial resolution in regions away from the equator. If sufficient signal-to-noise can be achieved, it may prove possible in the next decade to produce a global radar map of Mars with 20 km resolution. Such a map would be a tool for understanding the geomorphology of Mars, for selecting landing sites. Of course, a radar orbiter sent to map Mars would clearly improve the spatial resolution. It might not have the dual wavelength and multiple polarization capabilities of Earth-based radar observatories. Certainly the GSSR radar data would aid in the design of any such future mission.

Table 1. Planned GSSR Mars 2001 Observations

Date	Lat. (deg.)	Longitude (deg.) Rise	Set	Target
3 May	-1.83	321	35	'Haematite'
4 May	-1.83	312	24	'Haematite'
5 May	-1.82	302	15	'Haematite'
12 May	-1.61	250	304	Isidis/Syrtis
13 May	-1.56	240	294	Isidis/Syrtis
24 May	-0.55	132	182	'Stealth'
25 May	-0.42	123	172	'Stealth'
27 May	-0.14	102	151	'Stealth'
28 May	0.00	93	141	'Stealth'
7 June	1.70	355	39	'Haematite'
8 June	1.88	346	29	'Haematite'
9 June	2.07	336	19	'Haematite'
15 June	3.24	276	317	Isidis/Syrtis
17 June	3.63	257	297	Isidis/Syrtis
1 July	6.00	116	154	'Stealth'
2 July	6.13	106	144	'Stealth'
14 July	7.18	346	23	'Haematite'
19 July	7.31	245	332	Isidis/Syrtis

References: [1] Goldspiel J. M. et al. (1993) *Icarus, 106*, 346-364. [2] Moore H. J. and Thompson T. W. (1991) *LPS XXI*, 812-815. [3] Hagfors T., *JGR, 102,* 3779-3784. [4] Masursky H. and Crabill N. L. (1976) *Science, 193*, 809-812. [5] Tyler G. L. et al. (1976), *Science, 193*, 812-815. [6] Haldemann A. F. C. et al. (1997) *JGR, 102,* 4097-4106. [7] Haldemann A. F. C. et al. (1997) *EOS Trans. AGU, 78,* F404. [8] Ostro (1993) *Rev. Mod. Phys., 65,* 1235-1279. [9] Harmon J. K. (1998) *JGR, 104*, 14,065. [10] Harcke L. J. and Zebker H. A. (2000) *LPS XXXI,* abs.no 1770.

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